(12) UK Patent Application (19) GB (11) 2 218 677 (13) A

(43) Date of A publication 22.11.1989

(21) Application No 8910896.3

(22) Date of filing 11.05.1989

(30) Priority data
(31) 63119478 (32) 17.05.1988 (33) JP

(71) Applicant
Fuji Jukogyo Kabushiki Kaisha

(Incorporated in Japan)

7-2 Nishi-Shinjuku 1-chome, Shinjuku-ku, Tokyo-to, Japan

(72) Inventors
Atsushi Mine
Yutaka Hiwatashi
Katsuyoshi Kamimura

(74) Agent and/or Address for Service
Page White & Farrer
54 Doughty St, London, WC1N 2LS, United Kingdom

(51) INT CL⁴
B60G 17/00

(52) UK CL (Edition J)
B7D DCA

(56) Documents cited
None

(58) Field of search
UK CL (Edition J) B7D DCA DCT DCX
INT CL⁴ B60G
Derwent Publications' World Patents Index (online).

(54) **Pressure-compensated control of an active fluid suspension system for motor vehicles**

(57) A control for a fluid suspension system having a control valve assembly (5) through which fluid is forced from a high pressure reservoir (2) into a suspension unit (1) at each vehicle wheel (w) and is exhausted from the suspension unit into a low pressure reservoir (3). A controller (6) computes a desired amount of fluid to be introduced into or withdrawn from the suspension unit in response to vehicle condition sensors via the delivery or exhaust valve of the control valve assembly (5). The amount of fluid actually introduced into or exhausted from the suspension unit (1) varies owing to fluctuations in the pressure difference across the valve assembly. The fluctuations are monitored and the computed desired amount is corrected accordingly and the control valve assembly is actuated accordingly, in order that the amount actually introduced into or withdrawn from the suspension unit may closely approximate the desired amount.

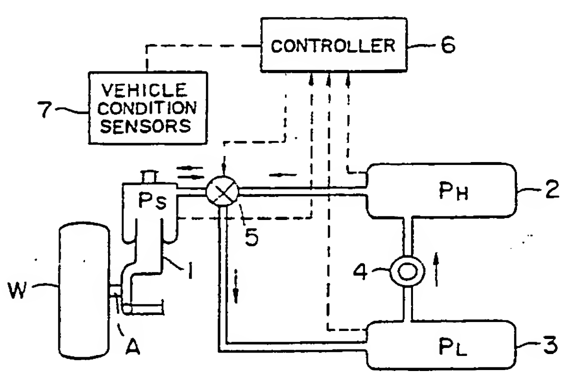


FIG. 1

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

GB 2 218 677 A

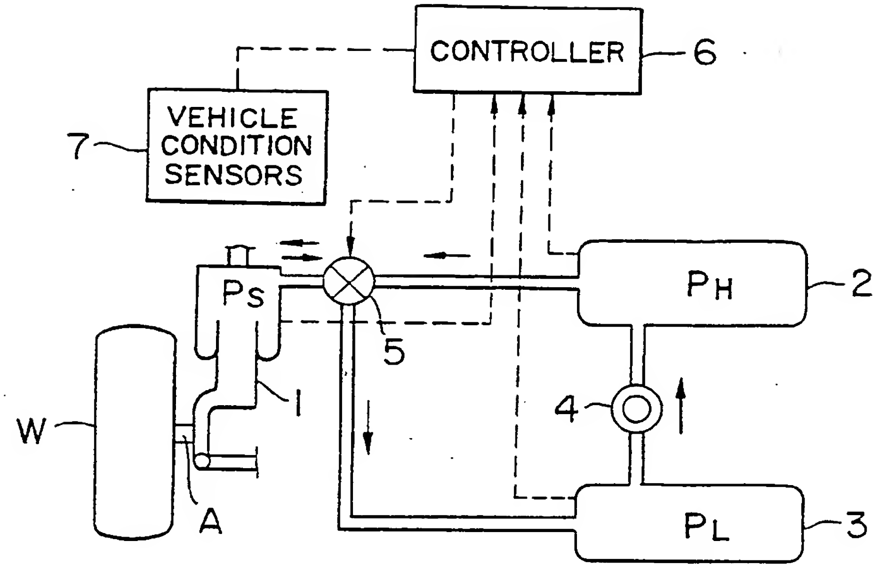


FIG. 1

FIG. 3

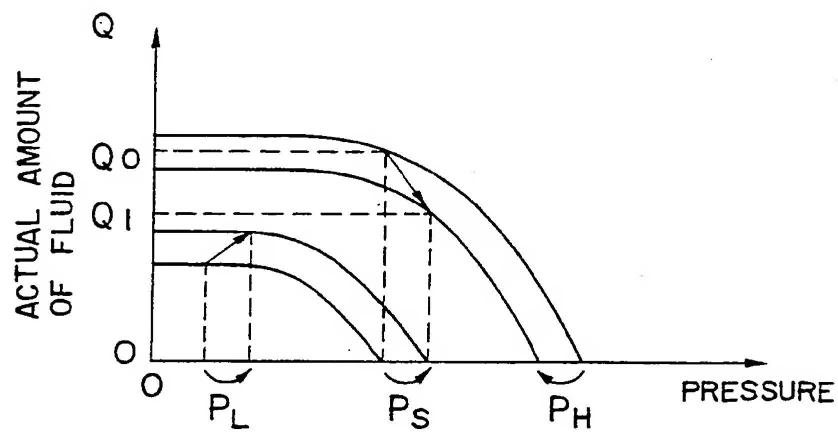
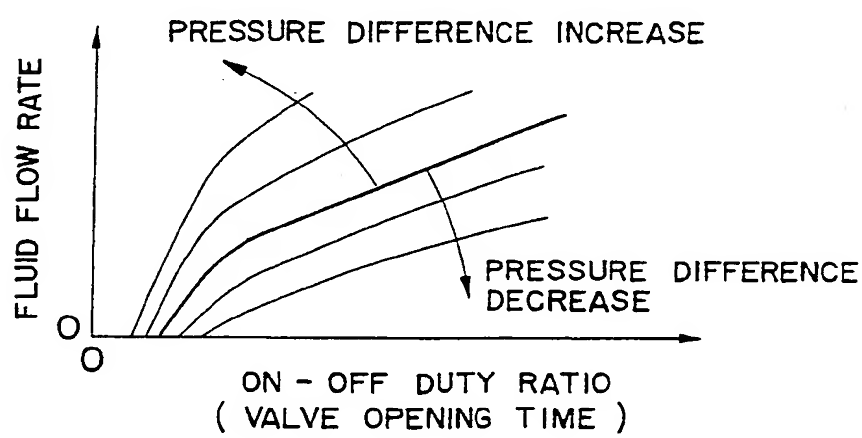


FIG. 5



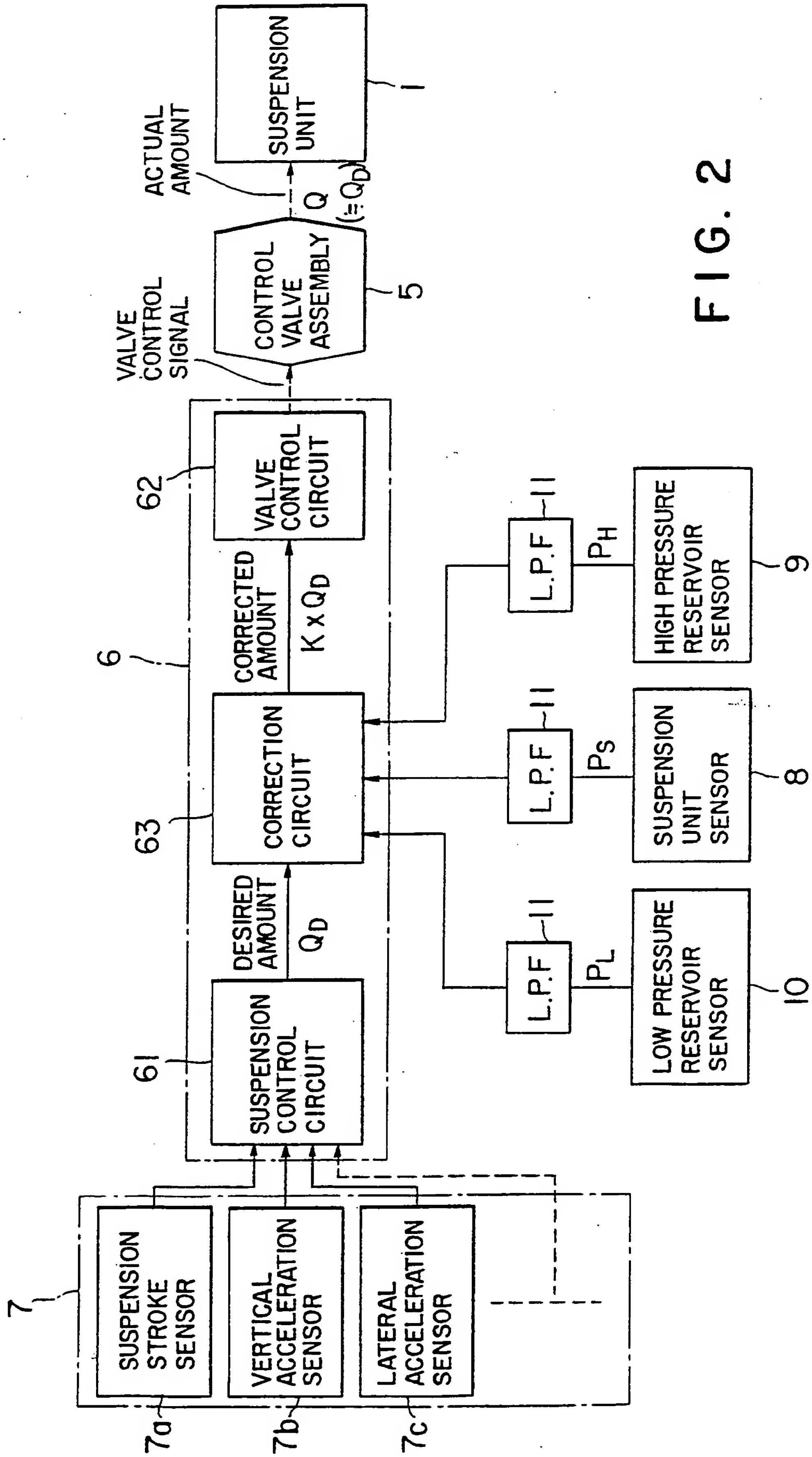
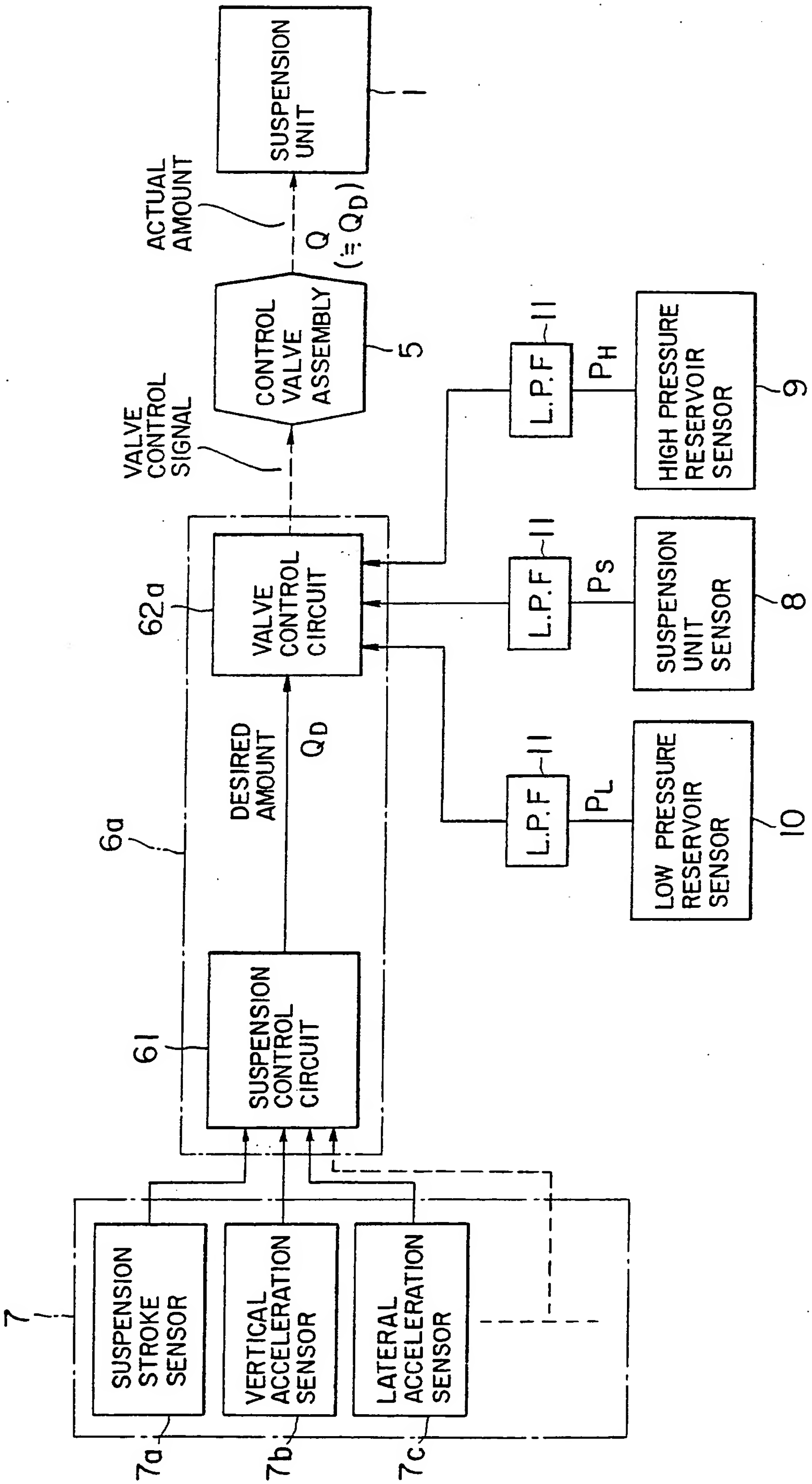

SUSPENSION UNIT
1
ACTUAL AMOUNT
Q (≒Q_D)
CONTROL VALVE ASSEMBLY
5
VALVE CONTROL SIGNAL
62
VALVE CONTROL CIRCUIT
CORRECTED AMOUNT
K x Q_D
6
63
CORRECTION CIRCUIT
DESIRED AMOUNT
Q_D
61
SUSPENSION CONTROL CIRCUIT
L.P.F
11
P_H
HIGH PRESSURE RESERVOIR SENSOR
9
P_S
SUSPENSION UNIT SENSOR
8
P_L
LOW PRESSURE RESERVOIR SENSOR
10
7
SUSPENSION STROKE SENSOR
7a
VERTICAL ACCELERATION SENSOR
7b
LATERAL ACCELERATION SENSOR
7c

FIG. 2



SUSPENSION STROKE SENSOR
VERTICAL ACCELERATION SENSOR
LATERAL ACCELERATION SENSOR
7
7a
7b
7c
SUSPENSION CONTROL CIRCUIT
61
6a
DESIRED AMOUNT
Q_D
VALVE CONTROL CIRCUIT
62a
VALVE CONTROL SIGNAL
CONTROL VALVE ASSEMBLY
5
ACTUAL AMOUNT
Q
($\doteqdot Q_D$)
SUSPENSION UNIT
L.P.F
11
P_L
P_S
P_H
LOW PRESSURE RESERVOIR SENSOR
10
SUSPENSION UNIT SENSOR
8
HIGH PRESSURE RESERVOIR SENSOR
9

FIG. 4

2218677

PRESSURE-COMPENSATED CONTROL METHOD AND APPARATUS FOR AN ACTIVE FLUID SUSPENSION SYSTEM FOR MOTOR VEHICLES

The present invention relates to a method of, and apparatus for controlling a fluid suspension system for motor vehicles, particularly an active suspension system for controlling the amount of fluid within the suspension units for vehicle wheels as required by various condtions of the vehicle.

An air suspension system for automatic level control mounted on the vehicle has been known, as taught for example by Japanese Utility Model Application Laid-Open (Kokai) No. 58-167208. The level control includes vehicle height sensors for detecting whether a relative displacement in height of the vehicle is above or below a predetermined position. Air is introduced into or withdrawn from the suspension units according to output signals of the vehicle height sensors so as to compensate for the sensed relative displacements and hence to level the vehicle.

Japanese Patent Application Laid-Open No. 62-139709 proposes a more sophisticated air suspension system. This system is referred to as the active suspension system and incorporates vehicle condition sensors for monitoring speed of the relative displacements, the

vertical acceleration of a mass above the spring of each suspension unit, and other vehicle conditions, in addition to the automatic level control means. The amount of air in each suspension unit is controlled in accordance with the sensed vehicle conditions for shock absorption and other purposes.

Typically, the active suspension system has a closed pneumatic circuit comprising: (a) a high pressure air reservoir for the delivery of air under pressure into the suspension units; (b) a low pressure air reservoir for recovering the air withdrawn from the suspension units; (c) an air compressor for drawing the air from the low pressure reservoir and repressurizing it for recirculation through the high pressure reservoir; and (d) a control valve assembly having both a delivery valve and an exhaust valve for introducing and withdrawing amounts of air into and from each suspension unit.

The control valve assembly is controlled by a controller. In response to the output signals of the vehicle sensors, the controller computes a desired amount of the air to be introduced into or exhausted from each suspension unit via the control valve assembly. The controller also responds to signals indicative of the air pressures within the high and low pressure reservoirs for controlling an on-off operation of the compressor. The compressor operates to maintain the air pressures in both reservoirs within predetermined limits.

There has, however, been a problem left unsolved with the prior art active suspension system. The problem arises from unavoidable fluctuations in pressure differential across the control valve assembly. Such fluctuations give rise to differences between each desired amount of air computed by the controller and an amount actually introduced into or withdrawn from each suspension unit, resulting in poor functioning of the suspension system.

The present invention has for its object to overcome the above problem of the prior art and provides an improved control method and apparatus for the active suspension system of the type described above whereby exactly desired amounts of fluid are charged into and exhausted from the suspension units.

The present invention provides a pressure-compensated control for an active fluid suspension system of the motor vehicle. In the present invention, computation is made to obtain a desired amount of a fluid to be introduced into or withdrawn from each suspension unit by monitoring a set of vehicle conditions. Also monitored is a fluid pressure differential across control valve means through which the fluid is to be introduced into or withdrawn from each suspension unit. The computed desired amount of fluid is corrected according to the fluid pressure differential across the control

valve means. The control valve means is then actuated according to the correction of the desired amount of fluid.

The air pressure within the suspension units and the reservoirs is subject to fluctuations during the operation of the active suspension system by such reasons as a change of the load on the vehicle and the displacement of the load during a vehicle turn or during a rapid vehicle acceleration or deceleration. The method of the present invention requires a constant monitoring of such fluctuations and an appropriate correction of the desired amount accordingly. Consequently, the amount of the fluid actually introduced into or withdrawn from the suspension units via the control valve means approximates the desired amount that has been computed. The active suspension system can thus be remarkably improved in performance.

Preferred embodiments of the present invention will become understood from the following detailed description referring to the accompanying drawings.

FIG. 1 is a schematic illustration of an active air suspension system the invention;

FIG. 2 is a block diagram of a system for controlling the suspension system of FIG. 1 according to the present invention;

FIG. 3 is a graph for explaining the operation of the suspension control system of FIG. 2;

FIG. 4 is a block diagram of another system for controlling the suspension system of FIG. 1, according to the present invention; and

FIG. 5 is a graph explaining the operation of the suspension control system of FIG. 4.

The present invention will now be described more specifically as adapted for controlling an air suspension system. Although FIG. 1 is a diagrammatic view and shows the active air suspension system as applied to only one representative vehicle wheel W, it will be seen that the system includes an air suspension unit 1 acting between the car frame, not shown, and each wheel axle A. The air suspension unit 1 communicates with both a high pressure air reservoir 2 and a low pressure air reservoir 3 via a control valve assembly 5. The high pressure reservoir 2 communicates with the low pressure reservoir 3 via an air compressor 4 for receiving pressurized air therefrom.

The control valve assembly 5 is a unitary combination of a delivery valve and an exhaust valve. Pressurized air is delivered from the high pressure reservoir 2 to the air suspension unit 1 when the delivery valve of the control valve assembly 5 opens. When the exhaust valve opens, on the other hand, the air is exhausted from the suspension unit 1 and directed to

the low pressure reservoir 3. The air thus charged into the low pressure reservoir 3 is recirculated, by being recompressed by the compressor 4 and supplied into the high pressure reservoir 2 again.

A controller 6 is electrically connected to the control valve assembly 5. The controller 6 receives signals from various vehicle condition sensors 7 of the active air suspension system, as well as from those built into the suspension unit 1 and reservoirs 2 and 3, as hereinafter set forth in detail. The delivery valve and exhaust valve of the control valve assembly 5 are opened and closed by the controller 6 in response to the various output signals of the sensor 7.

FIG. 2 is a block diagram showing how the controller 6 controls the control valve assembly 5 in accordance with the present invention. In the suspension unit 1, there are provided, typically, a suspension stroke sensor 7a, a vertical acceleration sensor 7b, and a lateral acceleration sensor 7c. The suspension stroke sensor 7a senses relative displacement of a mass above and below the spring part of the suspension unit 1. The vertical acceleration sensor 7b senses vertical acceleration of the vehicle above the spring part of the suspension unit 1. The lateral acceleration sensor 7c senses lateral acceleration of the vehicle.

In response to output signals from the vehicle condition sensors 7a, 7b, 7c, ..., the controller 6

computes a required amount of air to be introduced into, or exhausted from, the suspension unit 1. Based on such computations, the controller 6 delivers signals to the control valve assembly 5 for opening or closing its delivery and exhaust valves so as to introduce and exhaust the required amounts of air into and from the suspension unit 1.

It is understood that the delivery valve and the exhaust valve of the control valve assembly 5 are of the solenoid-actuated, normally closed type. The delivery and exhaust valves open on energization when the controller 6 dictates the delivery and exhaust, respectively, of air to and from the suspension unit 1. Basically, the amount of air introduced into and exhausted from the suspension unit 1 is determined by the period of time during which the delivery valve and exhaust valve are open. Therefore, upon computation of each required amount of air to be supplied or exhausted in response to the sensor output signals, the controller 6 determines the period of time during which the delivery valve or the exhaust valve is to be held open. The signals applied from the controller 6 to the control valve assembly 5 represent such periods of time. The controller 6 determines these periods of time on the bases of characteristics of average air flow rates versus time which are predetermined in consideration of the performance characteristics of the valves.

Ranges of air pressures P_H and P_L within the high pressure reservoir 2 and the low pressure reservoir 3 are preset to be sufficiently higher and lower, respectively, than the air pressure P_S within the suspension unit 1. The air compressor 4 operates both when the pressure P_H of the high pressure reservoir 2 drops to a lower limit of the preset range and when the pressure P_L of the low pressure reservoir 3 builds up to the upper limit of the preset range. The compressor 4 operates to draw air from the low pressure reservoir 3 and introduces the air into the low pressure reservoir 2, thereby maintaining the reservoir pressures P_H and P_L within the predetermined ranges.

Thus the reservoir pressures P_H and P_L change at least within the predetermined ranges. The suspension pressure P_S is also subject to change over a considerably great range depending upon vehicle load and other conditions.

Since such variations of the reservoir and the suspension pressures P_H, P_L and P_S are unavoidable, the flow rate of air through the control valve assembly 5 per unit time changes even though the performance characteristics of the control valve assembly 5 remain the same. Consequently, should the suspension system not incorporate the teachings of the present invention, the amounts of air actually introduced into and drawn from

the suspension unit 1 would deviate from the desired amount that have been computed by the controller 6.

From the foregoing considerations, the present invention proposes a novel suspension control method and an apparatus whereby the desired amounts of air that have been computed by the controller 6 are corrected as required by the relative pressures P_S, P_H and P_L of the suspension unit 1 and reservoirs 2 and 3. For this purpose, the suspension system additionally comprises a suspension unit pressure sensor 8, a high pressure reservoir pressure sensor 9 and a low pressure reservoir pressure sensor 10 for monitoring the pressures of the suspension unit and the reservoir. All these pressure sensors 8-10 are electrically coupled to the controller 6 for supplying signals indicating of the suspension unit pressure P_S and reservoir pressures P_H and P_L. Low-pass filters 11 are connected between the pressure sensors 8, 9 and 10 and the controller 6 for the removal of noise from the sensor signals. Supplied with the filtered sensor signals, the controller 6 is enabled to control the control valve assembly 5 for the delivery and exhaust of exactly desired amounts of air to and from the suspension unit 1, as explained in more detail hereafter.

As illustrated in FIG. 2, the controller 6 comprises a series connection of a suspension control circuit 61, a correction circuit 63 and a valve control circuit 62 for the practice of the method of the present invention. The

various vehicle condition sensors 7 are all connected to the suspension control circuit 61. In response to the output signals from these sensors 7 the suspension control curcuit 61 successively computes desired amounts Q_D of air to be supplied to or exhausted from the suspension unit 1. The correction circuit 63 is connected to the pressure sensors 8-10 and computes a correction coefficient or gain K from the sensed suspension unit pressure P_S and the reservoir pressures P_H and P_L. Then the correction circuit 63 multiplies each desired amount Q_D by the correction coefficient K and outputs a signal representing the corrected desired amount $K.Q_D$. The valve control circuit 62 responds to this output signal of the correction circuit 63 by opening the delivery valve or exhaust valve of the control valve assembly 5 during a period of time decided by the correction circuit output signal. The correction circuit 63 is interposed between the circuits 61 and 62 for carrying out the method of the present invention.

The operation of the controller 6 will be understood by reference to the graph of FIG. 3. Let it be assumed that the maximum flow rate of air through the delivery valve of the control valve assembly 5 (i.e. the flow rate when the delivery valve is fully open) drops from Q_0 to Q_1 in the event of a drop in the pressure P_H of the high pressure reservoir 2 and a rise in the pressure P_S of the suspension unit 1. Then, if the valve control circuit 62

were to control the opening time of the delivery valve in response to the suspension control circuit output signal representative of the desired amount Q_D, then the actual amount of air introduced into the suspension unit 1 would be $Q_1/Q_0 \times Q_D$ instead of Q_D.

The correction circuit 63 functions to compensate for such a difference between the desired and actual amounts of air introduced into the suspension unit 1. In response to the output signals of the suspension unit pressure sensor 8 and the high pressure reservoir pressure sensor 9, the correction circuit 63 keeps the rate of change Q_1/Q_0 of the flow rate, and a required correction coefficient K is obtained from a reciprocal Q_0/Q_1. Thus the correction circuit 63 delivers a signal indicative of the corrected amount $K \times Q_D = Q_0/Q_1 \times Q_D$ to the valve control circuit 62. The valve control circuit 62 makes on-off control of the delivery valve accordingly, in order that the amount of air Q actually admitted into the suspension unit 1 may closely approximate the desired amount Q_D that has been computed by the suspension control circuit 61.

Similar correction is also made for the withdrawal of air from the suspension unit 1. In this case the correction circuit 63 responds to the output signals of the suspension unit pressure sensor 8 and the low pressure reservoir pressure sensor 10. Since the flow rate of air through the exhaust valve of the control

valve assembly 5 is subject to change depending upon a relation between the suspension unit pressure P_S and low pressure reservoir pressure P_L, the correction circuit 63 derives the correction coefficiednt K from the input signals representing these pressures P_S and P_L. The correction coefficient K is used for the air delivery to the suspension unit 1 to minimize the difference between the desired and actual amounts of air withdrawn from the suspension unit 1.

The correction circuit 63 may renew the data representing the suspension unit pressure P_S and reservoir pressures P_H and P_L at predetermined time intervals of, say, three seconds. In practice such time intervals may be determined in consideration of the capacities of the reservoirs 2 and 3, the displacement of the compressor 4, and the amounts of air to be controlled.

FIG. 4 illustrates an alternative form of the suspension control system characterized by a controller 6a of modified circuit configuration. The modified controller 6a does not include the correction circuit 63 of FIG. 2 but have only the suspension control circuit 61 and a valve control circuit 62a. The suspension unit pressure sensor 8 and the reservoir pressure sensors 9 and 10 are connected to the valve control circuit 62a via respective low-pass filters 11. The other elements of

the system are the same as set forth above with reference to FIGS. 1 and 2.

The flow rate of air through the control valve assembly 5 changes in the event of a variation in the pressure of at least either of its upstream and downstream sides, even if the valve itself is constructed for a constant flow rate. FIG. 5 graphically shows how the relationship between the flow rate and the opening time of the delivery or exhaust valve of the control valve assembly varies with the changes in the pressure differential across the valve. Such valve characteristics of different typical pressure differential conditions may be digitally stored in the valve control circuit 62a in the form of "map".

At predetermined time intervals, the valve control circuit 62a may compare the sensor signals representing the air pressures on the upstream and the downstream sides of the control valve assembly 5, with the prerecorded data in the map. The high pressure reservoir 2 is upstream of the control valve assembly 5, and the suspension unit 1 is downstream of the control valve assembly 5 during the delivery of pressurized air into the suspension unit. The suspension unit 1 is upstream of the control valve assembly 5, and the low pressure reservoir 3 is downstream of the control valve assembly 5 during the withdrawal of air from the suspension unit 1.

Thus, for the delivery of a desired amount Q_D of pressurized air into the suspension unit 1, the valve control circuit 62a refers the high pressure reservoir pressure P_H and suspension unit pressure P_S to the prerecorded data stored in the map. Then the valve control circuit 62a causes the delivery valve of the control valve assembly 5 to open during a period of time determined in accordance with the data in the map. The control circuit 62a chooses a value closest to the present values of the upstream and downstream pressures P_H and P_S. The amount Q of air thus introduced into the suspension unit 1 will closely approximate the desired amount Q_D.

Similarly, for the withdrawal of a desired amount Q_D of air from the suspension unit 1, the valve control circuit 62a refers the suspension unit pressure P_S and low pressure reservoir pressure P_L to the prerecorded data in the map. Then the valve control circuit 62a causes the exhaust valve of the control valve assembly 5 to open during a period of time determined in accordance with the map. The circuit 62a selects a value closest to the present values of the upstream and downstream pressures P_S anmd P_L. The amount of air thus withdrawn from the suspension unit 1 will closely approximate the desired amount Q_D.

It is understood that the disclosure is for the purpose of illustration only and not to be taken in a

limitative sense. A various modifications or alterations will be readily considered. For example, while the illustrated suspension system employs a closed pneumatic circuit comprising the suspension unit 1, the air reservoirs 2 and 3, and the compressor 4, the principles of the invention may be applied to suspension systems of the type wherein the exhaust valve of the control valve assembly 5 is vented to the atmosphere, instead of being communicated with the low pressure air reservoir 3. The air compressor 4 draws air from the atmosphere in such an open pneumatic circuit. Since the atmospheric pressure can be considered constant for all practical purposes, the pressure difference across the control valve assembly 5 can be ascertained by sensing only the air pressures within the suspension unit 1 and high pressure reservoir 2 during both delivery and withdrawal of air to and from the suspension unit. The output signal of the suspension control circuit 61 is correctable in accordance with the thus-ascertained pressure difference.

It is also self-evident that the invention finds application to active suspension systems employing gases other than air as a cushioning medium. Above all, the invention is applicable to hydraulic or hydro-pneumatic suspension systems. Basically, such hydraulic or hydro-pneumatic system configurations can be the same as the air suspension system disclosed herein, except that the high pressure air reservoir is replaced by an

accumulator, and the low pressure air reservoir by a hydraulic fluid reservoir. A hydraulic pump draws the fluid from the reservoir and supplies it into the accumulator for storage therein under pressure, prior to delivery to the suspension unit.

The present invention is also applicable to the device described and claimed in Japanese Utility Model Application No. 62-135138 filed by the same assignee of the instant application. This prior application proposes a control valve assembly having provisions for controllably varying the flow rate of the fluid therethrough. Both the flow rate and the open time of the control valve assembly vary according to a desired amount of fluid provided by the controller by delivery to or withdrawal from the suspension unit. In practicing the method of the instant invention with this prior art device, the flow rate of the control valve assembly varies according to a sensed pressure difference across the valve assembly. The amount of fluid actually introduced into or exhausted from the suspension unit will then closely approximate the desired amount controlled by the suspension control circuit.

According to the present invention, computation is made to obtain a desired amount of a fluid to be introduced into or withdrawn from each suspension unit on the basis of a set of detected amounts of vehicle conditions. In addition to the above, fluid pressure

difference is detected across the control valve assembly through which the fluid is to be introduced into or withdrawn from each suspension unit, and the desired amount as stated above is corrected in dependency on the fluid pressure difference thus detected, whereby exactly desired amount of fluid is charged into and exhausted from the suspension unit to obtain proper functioning of the suspension system.

While the presently preferred embodiments of the present invention have been shown and described, it is to be understood that these disclosures is for the purpose of illustration and that various changes and modifications may be made without departing from the scope of the invention as set forth in the appended claims.

3. An apparatus for controlling an active fluid suspension system of a motor vehicle, comprising a fluid suspension unit (1) for each wheel (w) of the vehicle, control valve means (5) through which a fluid to be introduced into and withdrawn from the suspension unit is passed, condition sensor (7) for sensing a prescribed set of conditions of the vehicle, a suspension control circuit (61) for computing a desired amount of the fluid to be passed through said control valve means (5) and for delivering a signal of the desired amount, and a valve control circuit (62 or 62a) for receiving said signal and for actuating the control valve means so as to pass the desired amount of the fluid: characterized in that the apparatus further comprises pressure sensor means (8, 9 and 10) for sensing fluid pressure difference across the control valve means (5), and correction means (63 or 62a) for correcting said signal of the computed desired amount of the fluid in dependency on the sensed fluid pressure difference so as to make the amount of the fluid actually introduced into and withdrawn from the suspension unit (1) close to the desired amount.

4. The apparatus for controlling an active fluid suspension system according to claim 4, characterized in that said pressure sensor means comprises a sensor (8) for sensing fluid pressure in the fluid suspension unit, and sensors (9 and 10) for sensing fluid pressures in

CLAIMS:

1. A method of controlling an active fluid suspension system of a motor vehicle, wherein a fluid suspension unit (1) is provided for each wheel (w), wherein a set of conditions of the vehicle is sensed to compute a desired amount of a fluid to be introduced into and withdrawn from the suspension unit (1) through control valve means (5) on the basis of the detected conditions, and wherein the control valve means (5) receives a signal of said desired amount and is actuated to pass said desired amount of the fluid into and out of each suspension unit: characterized in that fluid pressure difference across the control valve means (5) is sensed, and said signal of the computed desired amount of the fluid is corrected in dependency on the fluid pressure difference so as to make the amount of the fluid actually forced into or withdrawn from the suspension unit (1) close to said desired amount.

2. The method of controlling an active fluid suspension system according to claim 1, characterized in that the fluid pressure difference is sensed by sensing fluid pressure in the suspension unit (1) and fluid pressures in high and low pressure fluid reservoirs (2 and 3).

high and low fluid pressure reservoirs (2 and 3), respectively, connected to the fluid suspension unit (1) via the control valve means (5).

5. The apparatus for controlling an active fluid suspension system according to claims 4 or 5, characterized in that said correction means is a correction circuit (63) connected between the suspension control circuit (61) and the valve control circuit (62).

6. A method of controlling an active fluid suspension system of a motor vehicle which method is substantially as hereinbefore described with reference to the accompanying drawings.

7. An apparatus for controlling an active fluid suspension system of a motor vehicle which apparatus is substantially as hereinbefore described with reference to the accompanying drawings.

Published 1989 at The Patent Office, State House, 66/71 High Holborn, London WC1R 4TP. Further copies may be obtained from The Patent Office. Branch, St Mary Cray, Orpington, Kent BR5 3RD. Printed by Multiplex techniques ltd, St Mary Cray, Kent, Con. 1/87